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PROGRESS REPORT

on

STUDIES OF THE PHYSICAL PROPERTIES OF TALC, THEIR MEASUREMENT, AND COMPARISON

to

JOHNSON AND JOHNSON

October 15, 1957

by

W. L. Smith

BATTELLE MEMORIAL INSTITUTE
505 King Avenue
Columbus 1, Ohio

K-3262-2 OK'd by O. F. Tangel and A. C. Richardson before typing.
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R. Anderson Files

Battelle Memorial Institute

505 KING AVENUE COLUMBUS 1, OHIO

October 25, 1957

Dr. W. H. Lycan
Director of Research
Johnson and Johnson
New Brunswick, New Jersey

Dear Dr. Lycan:

This letter transmits six copies of our report "Studies of the Physical Properties of Talc, Their Measurement, and Comparison".

At the present stage of this investigation it can be seen that the lubricity of the Italian talc is closely related to its purity, crystalline habit, and particle-size distribution and is expressed in bulk density, surface area, porosity, and average diameter measurements. The acceptable Italian talc was found to fall within a small range of physical measurements. Lubricity was found to be controlled by the shape of the relatively small content of comparatively larger particles in the otherwise finer mixture.

It appears feasible that the slip of the Italian talc may be improved by the removal of the coarser mineral contaminants.

Your comments on the findings of this investigation will be appreciated.

Very truly yours,

W. L. Smith

W. L. Smith
Principal Geologist
Minerals Beneficiation Division

WLS:rr
Enc. (6)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES
(Continued)

STUDIES OF THE PHYSICAL PROPERTIES OF TALC, THEIR MEASUREMENT, AND COMPARISON

by

W. L. Smith

SUMMARY

In order to improve the physical properties of talc it is necessary to be able to measure the differences in talc and to establish a basis for the determination of improvement. To study the lubricous property of talc, an experimental lubricity measuring device was built, and the behavior of different talc samples was compared with their other physical properties. The comparative physical measurements were made upon sized fractions and whole samples of Italian talc with conventional laboratory devices. It was found that the acceptable Italian talc fell within a small range of the physical measurements and that the samples with the more desirable slip have the greater surface area, the smaller average particle diameter, the greater ratio of voids to total volume, and the lesser bulk density. Lubricity was found to be controlled by the shape of the relatively small content of comparatively larger particles in an otherwise finer mixture. At the present stage of the investigation, the improvement of the slip of the Italian talc appears feasible by the removal of the coarser mineral contaminants.

INTRODUCTION

The talc currently used by Johnson and Johnson, obtained from Pinerolo, Italy, is believed to be a blend of five or more different grades of ore which gives a high quality, lubricous powder. In a proposal for research on the improvement of the properties of talc, dated June 4, 1956, it was proposed to study the basic properties of the acceptable Italian talc and to determine if and how the quality might be improved. The development of objective tests which might serve in the evaluation of talc was recommended, with the initial work to be done upon the product now used by Johnson and Johnson.

In order to determine improvement in the quality of talc, however, it is necessary to measure the apparently small differences between acceptable talc and talc of lower quality. Previously, measurements have been made by subjective methods only, which were thought to be of insufficient precision to measure small differences. The development and correlation of physical measurements has been undertaken to permit the measurement of improvement. The measurements of the physical properties of acceptable talc, and their range, have been made upon a series of one kilogram samples of grade "EGT Extra 00000" taken at weekly intervals from the conveyor at the Cranford, New Jersey, plant just before the talc enters the ribbon blendors. An additional large sample of talc was obtained for tests requiring larger volumes of material.

As a test for the comparative lubricity of talc samples, a lubricity board was constructed. This device, though not providing absolute values, gives reproducible

relative figures, with which the other physical properties, which can be more easily measured, may be correlated. This study, when coupled with proposed work on abrasiveness and other properties, should indicate the course to follow in beneficiation, the primary work on which Battelle reported in a letter dated June 12, 1957. The flotation work to date has been a laboratory expedient of producing talc of superior quality for physical tests.

DISCUSSION OF LUBRICITY

This report deals with lubricity and other physical properties including particle-size distribution and surface area, which are pertinent to lubricity. The desirable quality in talc, however, is only partly a matter of lubricity. That is, talc with the desired "feel" (as sensed subjectively) is not determined either by very high or very low lubricity (diminution of friction) but by a balance of physical properties which produces a particular sensory effect. This quality is referred to in this report as slip. The primary determining factor is the platiness of fine grained particles sliding over one another under slight pressure – not being lubricous in the sense of bearings which cut down friction by transmitting the moving forces to the rolling of an intermediate body, producing point friction; not being lubricous in the sense of a viscous fluid which buffers contact; but being lubricous in the sense of a series of leaves which impart the relative movement of two bodies along several planes parallel to the contact, producing the sensation of softness of surface contact.

The nature of the sliding of the platelets is a matter of kinetics, the changes in types of motion produced by applied forces. A certain intensity of force is required to maintain sliding between any two surfaces, and this varies with the nature of the surfaces. When the applied force is distributed along numerous planes rather than between two surfaces, the resistance to relative motion between the two bodies is distributed among a series of translation movements rather than in a rotational movement or in the overcoming of inertia in one plane. Inasmuch as the coefficient of sliding friction is apparently much less between talc platelets than between talc and flesh, the total friction resulting from the sum of translation movements is necessarily less than that of flesh in contact with flesh, and thus the lubricous property is sensed. The force producing the relative motion of two bodies is applied to the several planes of free moving talc platelets, which orient their greatest surfaces normal to the force applied; the contact of this series of parallel talc planes with flesh produces the silky or smooth sensation desirable in high quality talcum powder.

Grit (granular and acicular particles), where present, introduces point friction as in bearings, or plowing and thus is the primary objectionable contaminant in talcum powder.

The lubricousness or slip of talcum powder is determined by its mineralogical purity, the crystallographic habit of the talc, the size distribution of the powder, its moisture content, and the nature of the contaminants. Most of these factors must be determined petrographically, often on separated fractions of the powder. Other physical properties, such as surface area, average diameter, porosity, and bulk density, may be measured mechanically. Such physical measurements have been made, and the data have been correlated to determine which properties are significant in ground talc which has the desired slip. Measurements have been made to establish the

optimum limits of many of the properties relevant to lubricity. Data relevant to color, reflectance, moisture content, alkalinity, and abrasiveness will appear in a subsequent report.

THE ROLE OF MINERALOGICAL PURITY IN LUBRICITY

The Italian talc contains from about 97 to more than 99 per cent pure mineral talc. The predominant contaminant is carbonate, which is present in all size fractions, being slightly more abundant in the fines. Among other contaminants, present in trace amounts, are amphiboles, rutile, zircon, apatite, and titanite. The Italian talc is essentially free of opaques. The contaminants are generally prismatic or angular particles which act as grit and introduce point friction. A few such equidimensional or acicular particles present in an otherwise platy talcum, particularly if the grit is present in the coarser sizes, may be easily noticed subjectively. They diminish the lubricous feeling by the introduction of plowing, bearing-like particles, and the disruption of the lamellar movement of the talc particles. Inasmuch as the contaminants generally have diameters considerably greater than the thickness of talc platelets, their removal would improve the slip of any platy talc in which they occur in an effective amount. The small percentage of contamination in the Italian talc is an effective amount, as demonstrated by lubricity tests on a sample upgraded by froth flotation.

Further discussion of the nature of the impurities of talc was reported in earlier Battelle reports to Johnson and Johnson dated May 11, 1955[1]*, February 29, 1956[2], May 28, 1957[3], and July 25, 1957[4].

THE ROLE OF THE CRYSTALLOGRAPHIC HABIT OF TALC IN LUBRICITY

Platy talc is the most desirable for the purposes of the Sponsor. Whereas acicular and granular talc particles plow or roll, producing point friction, platy particles slide over one another producing the soft lubricous sensation desirable in talcum powder. The Italian talc averages about 10 per cent fibrous or acicular particles and about 90 per cent platelets. The amount of granular talc particles is negligible. Fibrous and granular particles of talc, though physically softer than the foreign mineral contaminants of talc ore, are none the less undesirable – if to a lesser degree. Such particles are most undesirable when present in the larger grain sizes where these crystals or aggregates may act as bearings or irritants.

Whereas different minerals may be separated from one another by physical processes, such as the removal of carbonates from talc by flotation, more difficulty is involved in separating particles of monomineralic, impalpable powder on the basis of their crystallographic habit, except where the crystal types concentrate in specific size fractions. Until beneficiation procedures for concentrating talc with the desired crystallographic habit are developed, talc which has the crystallographic habit preferred must be obtained by selective mining.

A detailed discussion of the various crystallographic habits of talc appears in a Battelle report to Johnson and Johnson dated February 29, 1956[2].

* References are given on page 23.

THE MEASUREMENT OF LUBRICITY

Discussion

Although the desired property of talc, the slip or optimum balance of size distribution and friction is only partly a matter of lubricity, it is correlative within certain limits of lubricity. A standard method of objectively measuring the lubricousness of talc has not been devised previously. The lubricity has been determined comparatively by feeling a pinch of powder between the fingers. People experienced in so testing talc subjectively are able to distinguish fine differences in quality. Since the desirable and undesirable qualities of talc are a subjective matter, it is likely that subjective testing is preferable. However, since the subjective tests are a matter of sensation, involving human reaction to several physical properties, such tests are of little help in devising methods of improving the physical properties of talc or of measuring small differences in particular properties. Because of this it was necessary to build a device to objectively test and measure lubricity, apart from the other properties which contribute to the desirability of talc.

It is not to be inferred that an objective test can replace the subjective test or that pleasantness of sensation is mechanically measurable; however, the physical properties which contribute to the unctuousness of talc can be measured and their optimum limits can be determined. Thus the means of improvement of talcs can be visualized. The figures obtained on the lubricity-board experiments are compared with the more easily made measurements of other physical properties in order to determine if there is a correlation and to establish the desirable limits of particular properties in acceptable Italian talc.

The Lubricity Board

In order to obtain quantitative measurements of talc samples, against which the measurements of other physical properties could be compared, a simple machine was constructed with a minimum of interacting physical factors. This device consists of a wooden plane inclined at 25 degrees, which is covered with talc (Figure 1). The lubricity is determined by measuring the time it takes a 226-gram steel puck to slide over two microswitches spaced 5 feet apart (Figure 2). The microswitches actuate an electric timer.

The lubricity board was designed as a preliminary device in making lubricity experiments; however, a routine method of measurement has been established and the device has demonstrated a reproducibility with an accuracy of more or less 1 per cent. Although more precise machines might be built, the lubricity board has proven to be an adequate means of measuring the comparative lubricity of talc samples and to be adequately precise for the comparison of data from other physical measurements. The measurements made on the lubricity board are presented in terms of .xxx second, the figures representing the average of fifty readings. A typical set of figures is shown in Table 1. A description of the lubricity board and the technique of its operation comprises Appendix A.

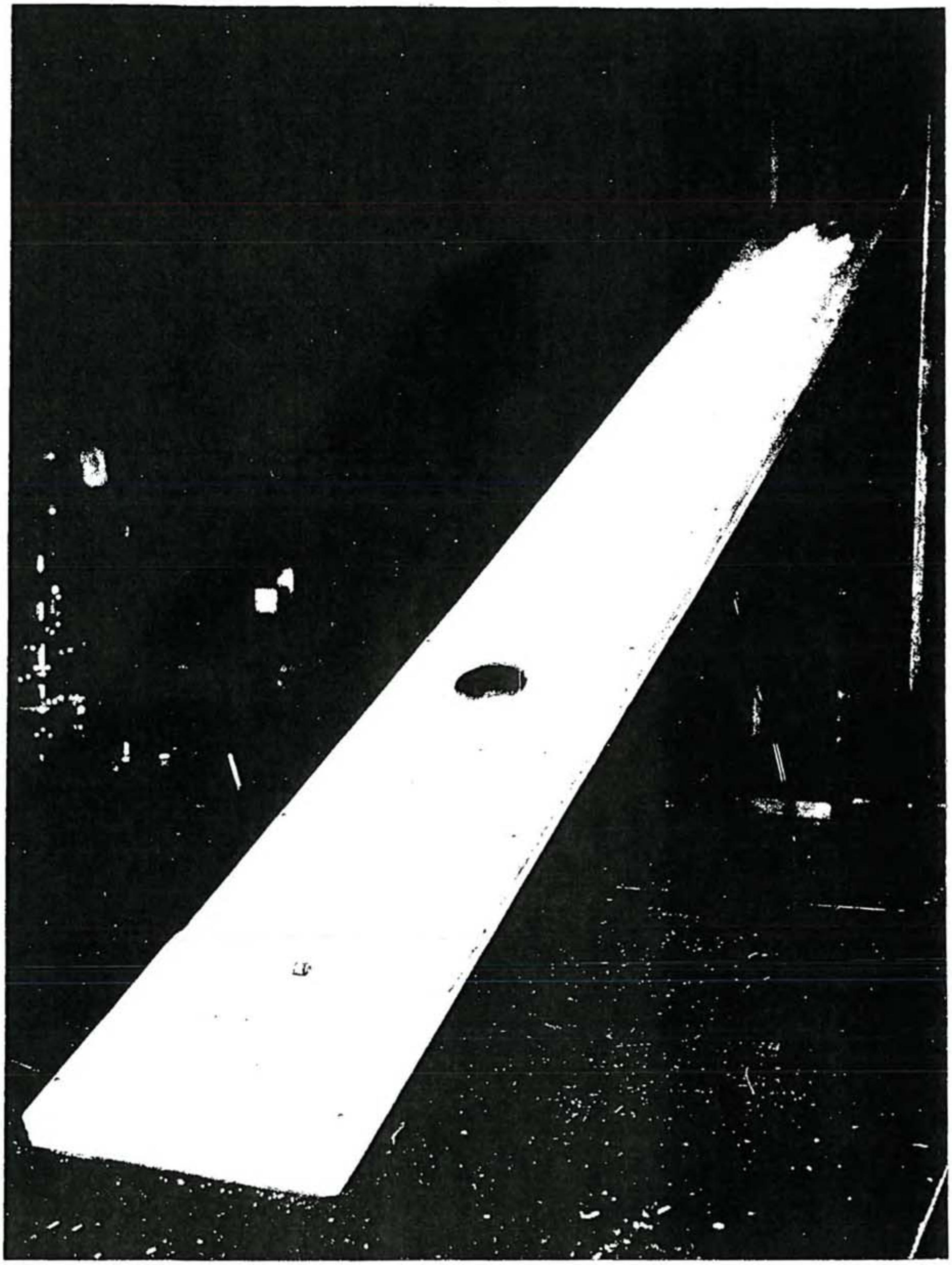

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FIGURE 1. THE LUBRICITY BOARD, SHOWING DESCENT OF STEEL PUCK

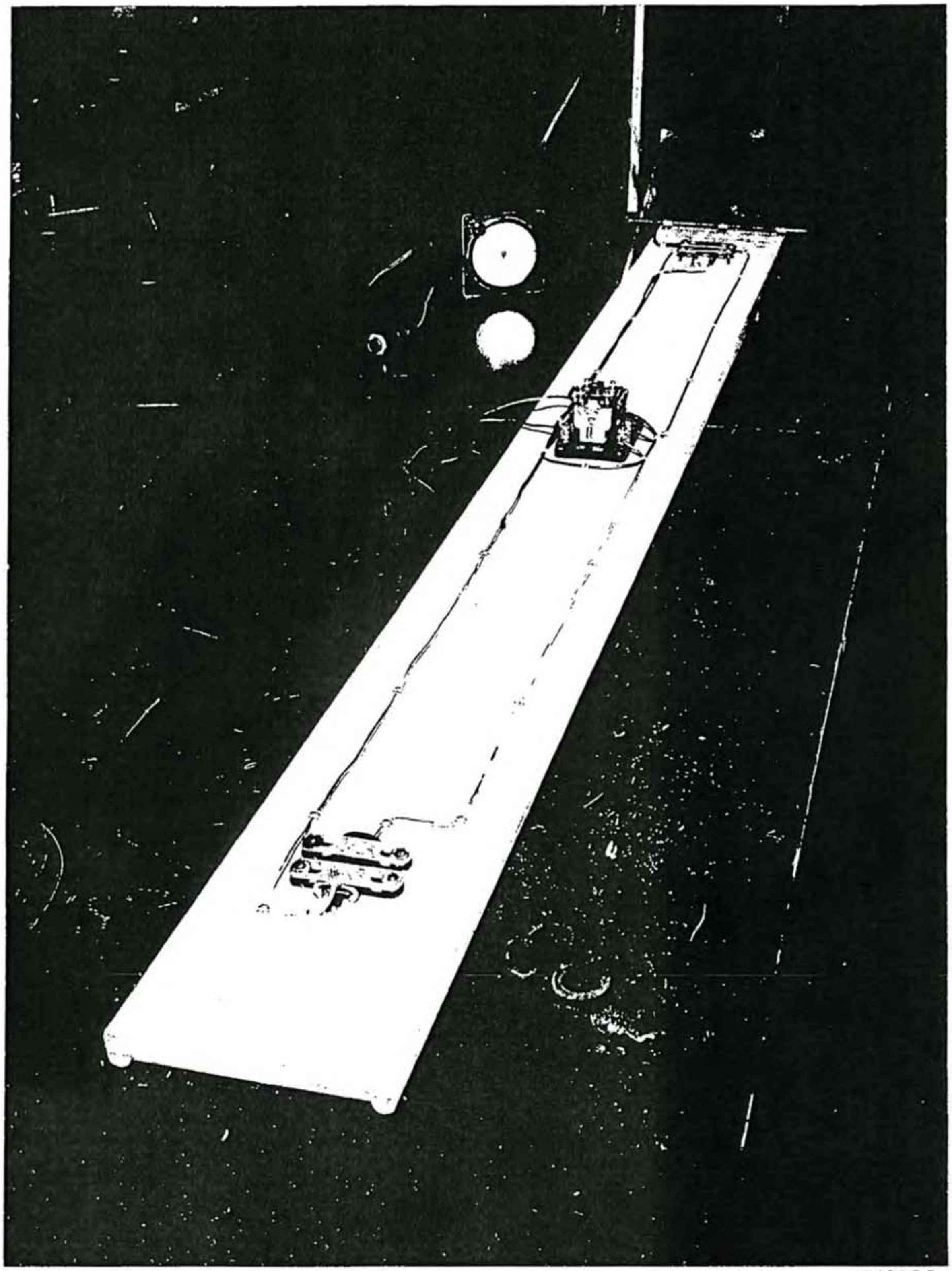

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FIGURE 2. UNDERSIDE OF LUBRICITY BOARD, SHOWING MICROSWITCHES AND ELECTRIC TIMER CONNECTED TO LOCK-IN RELAY

TABLE 1. TYPICAL DATA FROM LUBRICITY-BOARD MEASUREMENT OF ITALIAN TALC SAMPLE (CRANFORD, 12/22/56)

Measurement in Seconds				
Series 1	Series 2	Series 3	Series 4	Series 5
0.96[a]	0.97	0.98	0.97	0.97
0.98	0.96	0.97	0.96	0.97
0.95	0.96	0.97	0.96	0.96
0.95	0.95	0.97	0.98	0.95
0.97	0.96	0.96	0.98	0.96
0.97	0.95	0.96	0.97	0.94
0.96	0.96	0.97	0.96	0.97
0.95	0.97	0.98	0.98	0.98
0.97	0.96	0.97	0.97	0.95
0.94	0.97	0.97	0.99	0.97
Average 0.965 second				

(a) Lubricity board newly covered for each series of ten slides.

Contrary to preconceived ideas about the behavior of solid lubricants, the puck was found to slide faster on poorer grades of talc than on cleaner samples with better slip. The controlling factor is the presence of contaminants or equidimensional particles which act as bearings while purer talc, within the limits of the particular size distribution, presents a surface composed of flat platelets, producing more friction and slowing the descent of the puck.

It is not suggested at this time that Johnson and Johnson conduct similar experiments on a lubricity board. Until the lubricity studies are completed, it is intended that the lubricity board serve only as a basis for comparison with other measurements by which the physical properties which control lubricity can be evaluated.

The Lubricity of Talc Samples

Lubricity-board measurements were made on 15 samples of talc obtained from the Cranford plant of Johnson and Johnson, collected at regular intervals from August 10 to December 22, 1956. Table 2 lists the figures obtained for each sample. The readings ranged from 0.936 second for the sample which permitted the fastest descent of the puck to 1.083 seconds for that sample which most slowed the descent.

To test the hypothesis that the faster descents were due to bearing-like contaminants, the lubricity figures were compared to those of the percentage of contamination. Table 2 lists the amount of contamination as compared to the lubricity of the samples. The contamination figures represent microscopically identifiable particles and do not include the impalpable fines. Although correlation was not perfect, the relationship of contamination to lubricity is clear in the extreme instances. The talc containing the greater amount of contaminants permitted the faster descents on the lubricity board. The slight differences in contamination were not discernible subjectively.

TABLE 2. LUBRICITY-BOARD MEASUREMENTS AND PER CENT CONTAMINATION OF TALC SAMPLED AT CRANFORD, NEW JERSEY, SHOWING RELATION OF LUBRICITY TO PURITY OF SAMPLE

Date Sampled	Contamination[(a)], per cent	Lubricity-Board Measurements, seconds
9-6-56	<1	1.083 (slowest)
11-6-56	1	1.053
9-12-56	<1	1.030
9-19-56	<1	1.028
10-18-56	1	1.025
8-10-56	1	1.021
9-27-56	1	1.017
8-28-56	2	1.007
10-29-56	1-2	1.006
10-4-56	1-2	0.982
8-20-56	2	0.971
10-12-56	2-3	0.968
12-22-56	2	0.965
11-30-56	2-3	0.952
11-15-56	2	0.936 (fastest)

(a) Determined petrographically.

Inasmuch as the contamination figures were small, were close together, and could be prejudiced, the contaminants were removed from a sample of talc by froth flotation and the products were tested on the lubricity board. The test results, which are also noticeable subjectively, are given in Table 3.

TABLE 3. LUBRICITY-BOARD DATA ON FLOTATION PRODUCTS OF ITALIAN TALC, SHOWING DELETERIOUS EFFECT OF CONTAMINATION ON LUBRICITY

Product	Lubricity-Board Measurement, seconds
Starting sample	0.990
Float product[(a)]	1.046 (superior)
Nonfloat product[(b)]	0.873 (inferior)

(a) Essentially pure talc, representing 90 per cent of starting sample.
(b) 85 per cent talc, 15 per cent contaminants, representing 10 per cent of starting sample.

The essentially pure talc product produced a slower descent of the steel puck than did the unseparated sample, and the flotation tailings permitted a descent considerably faster than did the unseparated sample. It may be concluded, on the basis of several experiments on the lubricity board, that the purer talc with the better slip requires a longer time for the puck to slide, while the samples more contaminated with granular "bearings" permit faster descents. Although the details of practical beneficiation of this talc by froth flotation have yet to be worked out, the amenability of the talc to

flotation and the obvious improvement in the purity and slip of the product indicate that beneficiation is a feasible consideration for the improvement of the Italian talc.

C THE RELATIONSHIP OF LUBRICITY TO PARTICLE-SIZE DISTRIBUTION

Discussion

The desirable slip in talcum powder does not depend alone on the physical lubricity of the mineral but on numerous interdependent physical properties, one of the more important being particle-size distribution. The relative amount of grains in different size fractions, the extreme sizes, and the crystalline habit of grains of different sizes play a major role in lubricity. Comparatively larger grains in an otherwise fine powder may roll like bearings, plow, or act as barriers to the free movement of smaller platelets. Too large an amount of very fine grains may behave as "flour" despite their particle shape and may disrupt or may clog the movements of larger platelets.

Size distribution is reflected in bulk density, porosity, surface area, and average diameter measurements. The samples of Italian talc were found to have physical properties which fall within a small range of many of these measurements and which can be related to lubricity in some instances. Too many variable properties exist in talc to assess specific requirements for many physical measurements; however, in testing for acceptable talcs, those ores with properties similar to the Italian talc should also be expected to have measurements within or close to the range of those obtained on the Italian talc. The measurements should be a useful guide in the blending of talcs and for the rejection of inferior grades.

Battelle wishes to emphasize that immediate conclusions should not be drawn from the following physical measurements alone, inasmuch as they represent but half of the story. A forthcoming report which will deal further with lubricity and other physical properties such as whiteness, abrasiveness, and moisture content, will expand the list of the properties required for an acceptable talc. Although many talcs may be rejected because they fail to meet certain physical requirements presented here, acceptability involves additional factors.

Particle-Size Distribution in Italian Talc

In a previous report to Johnson and Johnson[(2)], Battelle reported a dry screen analysis and a particle-size distribution of Italian talc based on both dry screening and sedimentation in water. These findings are repeated in Table 4. Further, extensive particle-size distribution studies were made showing that three replicate analyses of a large sample of Italian talc were closely reproducible and in close agreement with the earlier analyses, although obtained from a separate sample (Table 5). Appendix B contains a description of the procedure for particle-size analysis.

TABLE 4. PREVIOUSLY REPORTED PARTICLE-SIZE DISTRIBUTION DATA(2) ON ITALIAN TALC

a. Dry Screen Analysis

Tyler Mesh Size	Weight Per Cent
+150	0.1
-150+200	1.8
-200+270	2.1
-270+325	13.5
-325	82.5
	100.0

b. Approximate Particle-Size Distribution Based on Dry Screening and Sedimentation in Water

Size	Approximate Weight Per Cent
-100+200 Mesh	2
-200+325 Mesh	16
-325 Mesh + 15 Microns	62
-15 Microns + 10 Microns	9
-10 Microns	11
	100

TABLE 5. PARTICLE-SIZE DISTRIBUTION OF THREE SAMPLES OF ITALIAN TALC

Size	Average Weight Per Cent	Per Cent Deviation From Mean
+200 mesh[a]	1	0.12
-200 mesh + 325 mesh	10	0.97
-325 mesh + 400 mesh (38 microns)	7	1.3
-38 microns + 30 microns	57	5.18
-30 microns + 15 microns	12	0.8
-15 microns	13	3.1
	100	

(a) Tyler.

To check the variation in particle-size distribution of the talc samples from Cranford, a series of measurements by dry screening and sedimentation were made on 12 samples. Table 6 lists the weight per cent of each size fraction. One of the samples, Cranford 10/4/56, might be eliminated statistically from the sample population; however, the variation is real and its data are included in the weight per cent deviation from the mean (Table 7). The effect of the variant sample shows clearly in the measurements of average particle size, specific surface, bulk density, and porosity (Tables 12, 15). The cause of the variation is not obvious petrographically, the sample being similar to the others except in size distribution. This variant sample demonstrates that the Pinerolo product is not uniform. Also, since the larger coarse fraction does not cause the expected effect on the lubricity measurement as do variations within the normal size distribution population, it shows that the matter of lubricity is more complex than is indicated by variations within a small range in particle-size distribution.

The Cranford samples have minor variations in particle-size distribution. In all of the samples, however, the -400 mesh (38 micron) + 30 micron fraction constitutes about one-half of the sample, with minor amounts in the smaller and larger fractions. This distribution should be kept in mind should platy talcs of other distributions be considered. Inasmuch as the size distribution may be as much a matter of the grinding and blending of ores as of the physical nature of the ore, fabrication of acceptable talcum powder from lower grade ore might be accomplished by a proper blend of sized fractions of platy talc.

Correlation of Lubricity With Particle-Size Distribution Data

In order to correlate the particle-size distribution and lubricity data, a large sample of Italian talc was sized and the size fractions were tested on the lubricity board. Experiments clearly showed that the coarser fractions permitted a faster descent of the puck while the finer fractions produced a slower descent. This is apparently due to the more equidimensional bearing-like particles in the coarser fractions. Table 8 demonstrates the relationship of particle size to lubricity, showing the larger, more desirable, lubricity figures for the fines, the lower for the coarser, gritty fraction.

Inasmuch as the lubricity of talc involves the physical properties of material of various grain sizes, lubricity measurements were made on various proportional mixtures of specific particle-size fractions and on powders from which specific particle-size fractions were removed. In order to determine if the over-all lubricity was controlled by the coarse or by the fine sizes, a series of lubricity measurements was made on proportional mixtures of the fine (-400 mesh) and coarse (+250 mesh) sizes. Table 9 clearly shows that the control is in the relative amount of coarser to finer grains. That is, a small amount of coarse particles added to an otherwise fine powder has a pronounced adverse effect on lubricity, whereas a similar percentage addition of fine particles to an otherwise coarse grained powder has comparatively little effect on lubricity. It may be concluded from this study that the removal of the coarser particles, which tend to be more equidimensional, will improve the slip. On the other hand, the addition of fines to gritty or granular powders makes comparatively little improvement.

TABLE 6. PARTICLE-SIZE DISTRIBUTION OF TALC SAMPLED AT CRANFORD PLANT

	Weight Per Cent of Size Fractions					
Date Collected	+200 Mesh	-200 Mesh +325 Mesh	-325 Mesh +400 Mesh	-400 Mesh +30 Microns	-30 Microns +15 Microns	-15 Microns
9-6-56	0.47	5.44	6.83	65.72	10.76	10.78
11-6-56	0.51	5.13	7.75	56.66	16.49	13.46
9-12-56	0.92	8.30	7.85	60.76	10.23	11.94
9-19-56	0.84	5.54	7.65	55.79	16.42	13.88
10-18-56	0.96	7.86	7.27	58.07	13.32	12.52
9-27-56	0.59	4.48	6.77	56.52	15.93	15.71
8-28-56	0.50	4.34	6.89	56.39	16.18	15.71
10-4-56(a)	1.22	6.38	9.36	40.02	31.74	11.28
8-20-56	0.65	6.08	7.98	57.53	16.64	11.12
12-22-56	0.88	3.42	12.30	52.27	20.01	11.12
11-30-56	0.72	6.38	10.33	57.86	11.21	13.50
11-15-56	0.88	6.93	9.91	48.72	22.08	11.48

(a) See comment under "Particle-Size Distribution in Italian Talc".

TABLE 7. DEVIATION IN PARTICLE-SIZE DISTRIBUTION IN WEIGHT PER CENT OF TALC SAMPLED AT THE CRANFORD PLANT

Size	Deviation, weight per cent (Excluding Sample 10/4/56)	Deviation, weight per cent (Including Sample 10/4/56)
+200 mesh[a]	0.26	0.39
-200 mesh + 325 mesh	2.44	2.44
-325 mesh + 400 mesh (38 microns)	1.78	1.78
-38 microns + 30 microns	8.50	12.85
-30 microns + 15 microns	5.42	10.75
-15 microns	3.72	3.72

(a) Tyler.

TABLE 8. RELATIONSHIP OF LUBRICITY TO PARTICLE SIZE

Tyler Mesh Size	Lubricity-Board Measurement, seconds
Unseparated	0.990
+200	0.889
-200+250	0.951
-250+270	0.980
-270+325	1.030
-325+400	1.043
-400	1.099

TABLE 9. THE LUBRICITY OF MIXTURES OF COARSE AND FINE SIZES OF TALC, DEMONSTRATING THE CONTROL TO BE IN THE COARSE FRACTIONS

Per Cent Fines (-400 Mesh)	Per Cent Coarse (+250 Mesh)	Lubricity-Board Measurement, seconds	Difference in Lubricity
0	100	0.951	
			.000
10	90	0.951	
			.009
25	75	0.960	
			.010
50	50	0.970	
			.016
75	25	0.986	
			.052
90	10	1.038	
			.061
100	0	1.099	

Further measurements of the effect of particle-size distribution on lubricity were made by testing whole powder from which different size fractions had been removed. The measurements, Table 10, demonstrate that removal of the fines decreases the quality of the powder, whereas removal of the coarse fractions improves it. It would have to be determined by further tests of beneficiation products whether it is most advisable to remove entire size fractions or merely the small percentage of coarse contaminants.

TABLE 10. LUBRICITY MEASUREMENTS OF ITALIAN TALC SAMPLES FROM WHICH SPECIFIC PARTICLE-SIZE FRACTIONS HAVE BEEN REMOVED

X Represents Fractions Removed From Whole Powder
U Represents Fractions Tested

Tyler Mesh Size	Lubricity-Board Measurement of[a] Size Fractions	Test 1	Test 2	Whole Powder	Test 3	Test 4
+200	0.889	U	U	U	X	X
-200+250	0.951	U	U	U	X	X
-250+270	0.980	U	U	U	U	X
-270+325	1.030	X	U	U	U	U
-325+400	1.043	X	U	U	U	U
-400	1.099	X	X	U	U	U
Lubricity-Board Measurement		0.945	0.963	0.990	1.038	1.068
				Increase in slip →		
Approximate Weight Per Cent of Fractions Removed		97.	82.	0.	2.	3.

(a) Repeated from Table 8 for comparative purposes.

MOISTURE CONTENT

Of considerable importance to the lubricity of talc is its moisture content. This topic is more thoroughly treated in a forthcoming report. It is important, however, to note here that an increase in moisture content slows the descent of the puck on the lubricity board and falsely indicates superior lubricity. All of the Italian talc was found to contain a moisture content in the hundredths of one per cent. Analyses of various size fractions show that the moisture content is higher in the fine sizes, possibly due to adsorption on the greater surface area.

MEASUREMENT AND CORRELATION OF OTHER PHYSICAL PROPERTIES RELATED TO LUBRICITY

Surface Area Determinations by Nitrogen Adsorption

The relationship of lubricity to particle-size distribution has been shown to be a matter of friction and surface area, the finer platelets having the greater surface area per unit of weight.

Four samples of Italian talc from Cranford were measured for their surface area using the Brunauer, Emmett, Teller technique of nitrogen adsorption at liquid nitrogen temperatures (Table 11).

TABLE 11. SURFACE AREA MEASUREMENTS OF ITALIAN TALC, COMPARED WITH LUBRICITY-BOARD MEASUREMENTS

Cranford Sample Date	Lubricity-Board Measurement, seconds	BET Surface Area Measurement, m^2/g
9-6-56	1.083	3.57
9-12-56	1.030	3.18
9-19-56	1.028	2.93
10-4-56	0.982	2.26

The tests show a relationship between surface area and lubricity, the samples with the greater surface area also having the larger lubricity measurements. The values are believed to be accurate to within 5 per cent.

Average Diameter of Particles

An easily operated instrument for rapid particle-size determinations is the Fisher Subsieve Sizer. The instrument measures average particle size by determining the resistance to the flow of air by a weighed sample of powder under standard packing conditions. On the basis of the principle that a fluid meets less resistance to flow while

TABLE 12. COMPARISON OF THEORETICAL AVERAGE-DIAMETER MEASUREMENTS AND SPECIFIC SURFACE TO LUBRICITY-BOARD MEASUREMENTS OF CRANFORD SAMPLES

Cranford Collection Date	Lubricity-Board Measurement, seconds	Theoretical Average[b] Particle Diameter	Specific Surface, cm^2/g
9-6-56	1.083	2.60	8392
11-6-56	1.053	2.65	8233
9-12-56	1.030	2.60	8392
9-19-56	1.028	2.45	8905
10-18-56	1.025	2.60	8392
8-10-56	1.021	2.80	7792
9-27-56	1.017	2.80	7792
8-28-56	1.007	2.75	7934
10-29-56	1.006	2.80	7792
10-4-56[a]	0.982	3.30	6612
8-20-56	0.971	2.90	7524
10-12-56	0.968	2.90	7524
12-22-56	0.965	3.10	7038
11-30-56	0.952	3.30	6612
11-15-56	0.936	3.20	6818

(a) See comment under "Particle Size Distribution in Italian Talc".
(b) Determined on Fisher Subsieve Sizer.

penetrating a bed of coarse particles than while penetrating a bed of fine particles, a figure is derived which disregards the shape of the individual grains, porosity, size distribution and other variables. Inasmuch as the average diameter figure represents a theoretical sphere, the data are of relative rather than actual value. Average diameter measurements made on the Fisher Subsieve Sizer are shown in comparison with lubricity measurements (Table 12), demonstrating the correlation of small average diameters to talc with the larger lubricity measurement and larger average diameters to talc with the lower, less desirable, lubricity measurements. A clear-cut correlation of the theoretical average-particle-diameter measurements with the lubricity-board measurements is shown in Table 13.

TABLE 13. RELATIONSHIP OF LUBRICITY-BOARD MEASUREMENTS TO THEORETICAL AVERAGE DIAMETERS ON SIZED FRACTIONS OF ITALIAN TALC

Tyler Mesh Size	Lubricity-Board Measurements, seconds	Theoretical Average Particle Diameter, microns(a)
Unseparated	0.990	2.60
+200	0.889	7.40
-200+250	0.951	3.60
-250+270	0.980	2.50
-270+325	1.030	2.35
-325+400	1.043	2.25
-400	1.099	2.10

(a) Determined on Fisher Subsieve Sizer.

Specific Surface Calculated From Average Diameter

The average particle diameter as determined on the Fisher Subsieve Sizer may, by use of a simple equation,* be expressed in terms of specific surface in square centimeters per gram of dry powder. This is a simpler, less expensive method than nitrogen adsorption. Specific surfaces, as calculated from the average-particle-diameter measurements, are presented in Table 12 in comparison with lubricity. The calculated specific-surface figures, because of their derivation from average-particle-diameter measurements, are inversely correlative with particle size. The samples with the greater specific surfaces are those which impede the slide of the puck on the lubricity board, and which have better slip, while the samples with the smaller specific surfaces, those containing the larger particles, are the samples permitting faster descents of the puck on the lubricity board.

As in the case of the average particle-diameter measurement, the specific-surface calculations represent theoretical spheres which, since the powder is composed of platelets, are of relative rather than exact value. Whereas the surface area as determined by gas adsorption is relatively exact, the value of the surface-area figures derived from the theoretical average-particle-diameter measurements is purely comparative.

*Specific surface (cm^2/g) $= \dfrac{6 \times 10^4}{\text{average diameter } (\mu) \times \text{specific gravity of talc}}$.

The relationship of specific surface to the lubricity of sized fractions of Italian talc is presented in Table 14, which shows that the fractions with the better lubricity also have the greater surface areas.

TABLE 14. CORRELATION OF SPECIFIC SURFACE AND LUBRICITY-BOARD MEASUREMENTS OF SIZED FRACTIONS OF ITALIAN TALC

Tyler Mesh Size	Lubricity-Board Measurements, seconds	Specific Surface, cm^2/g
Unseparated	0.990	8392
+200	0.889	2948
-200+250	0.951	6061
-250+270	0.980	8727
-270+325	1.030	9284
-325+400	1.043	9697
-400	1.099	10390

Porosity

A measurement of porosity, independent of the other measurements, may be made on the Fisher Subsieve Sizer. The porosity figure represents the ratio of voids to the total volume of the packed sample, in a range of 0.40 to 0.80. Inasmuch as part of the test involves a manual operation, the results are subject to a human error. The porosity figures, however, are reproducible through the second decimal place. The range in porosity, 0.448 to 0.490, determined on the Cranford samples, is a relatively small range and should, by its close limits alone, be of assistance in evaluating Italian talc (Table 15). The more porous powders, those with the greatest amount of asymmetrical, platy grains, are also those with the larger lubricity-board measurements, hence the better slip. Correspondingly, the samples with the lower porosity, those containing the greater amount of equidimensional grains, are the powders which have the lower lubricity-board measurements.

Table 16 shows the porosity of sized fractions of Italian talc as compared with its lubricity-board measurements. The porosity is clearly shown to be less in the coarser fractions with the poorer slip and greater in the finer fractions.

TABLE 15. POROSITY, BULK DENSITY, AND LUBRICITY OF CRANFORD SAMPLES

Cranford Collection Date	Porosity Ratio	Bulk Density, lb/cu ft	Lubricity-Board Measurements, seconds
9-6-56	0.490	22.942	1.083
11-6-56	0.480	22.958	1.053
9-12-56	0.475	23.259	1.030
9-19-56	0.456	23.437	1.028
10-18-56	0.452	22.860	1.025
8-10-56	0.460	23.528	1.021
9-27-56	0.464	23.096	1.017
8-28-56	0.470	22.642	1.007
10-29-56	0.461	22.491	1.006
10-4-56[a]	0.475	24.061	0.982
8-20-56	0.460	23.756	0.971
10-12-56	0.455	23.429	0.968
12-22-56	0.452	22.616	0.965
11-30-56	0.448	22.725	0.952
11-15-56	0.450	22.583	0.936

(a) See comment under "Particle-Size Distribution in Italian Talc".

TABLE 16. CORRELATION OF POROSITY AND LUBRICITY-BOARD MEASUREMENTS OF SIZED FRACTIONS OF ITALIAN TALC

Tyler Mesh Size	Lubricity-Board Measurements, seconds	Porosity Ratio
Unseparated	0.990	0.448
+200	0.889	0.401
-200+250	0.951	0.426
-250+270	0.980	0.439
-270+325	1.030	0.446
-325+400	1.043	0.442
-400	1.099	0.455

Bulk Density

The bulk density of ground talc may be measured on a Scott Volumeter. The Cranford talc samples were found to have bulk densities ranging between 22 and 25 pounds per cubic foot. Table 15 lists the bulk densities of the Cranford talc samples. The bulk-density measurement is not precise enough to accurately compare small differences but is valuable in establishing a range of acceptability. When sized fractions are tested, the bulk density is seen to have inverse relationships with porosity and specific surface and to have a direct relationship with average particle size. Thus, as shown in Table 17, bulk density is inversely correlative with lubricity as a function of particle size. The coarser fractions, with poorer slip have the higher bulk density; the finer fractions having the lower bulk density. The relationship of bulk density, moisture content, and lubricity is presented in a forthcoming report.

TABLE 17. THE RELATIONSHIP OF BULK DENSITY TO LUBRICITY-BOARD MEASUREMENTS OF SIZED FRACTIONS OF ITALIAN TALC

Tyler Mesh Size	Lubricity-Board Measurements, seconds	Bulk Density, lb/cu ft
Unseparated	0.990	23.030
+200	0.889	34.261
-200+250	0.951	26.645
-250+270	0.980	20.721
-270+325	1.030	19.335
-325+400	1.043	19.139
-400	1.099	16.894

CONCLUSIONS

Because this study represents but part of the picture of evaluating acceptable talc by means of its physical properties, it is not possible to state final conclusions without qualifications. Several relationships between physical properties, however, have been established for acceptable Italian talc and the range of their variations have been measured. A forthcoming report including studies of other physical properties will add to the picture and will indicate the course to follow for beneficiation of the Italian talc in order to improve its physical properties.

The physical properties of the Italian talc samples have been measured and the following ranges in values were obtained:

(1) Contamination: from less than 1 to more than 3 per cent.

(2) Crystallographic habit: more or less constantly 90 per cent platy, 10 per cent fibrous.

(3) Lubricity-board measurement: from 0.936 to 1.083 seconds.

(4) The ratio of voids to total volume: from 0.45 to 0.49.

(5) Theoretical average particle diameter: from 2.45 to 3.30 microns.

(6) Bulk density: from 22.49 to 24.06 lbs/cu. ft.

(7) Specific surface: from 6612 to 8905 cm^2/g.

(8) Moisture content: hundredths of one per cent.

(9) Particle-size distribution:

+200 mesh	0.47 to 1.22 per cent
-200+325 mesh	3.42 to 8.30
-325+400 mesh (38 microns)	6.77 to 10.33
-38 microns + 30 microns	40.02 to 65.72
-30 microns + 15 microns	10.23 to 22.08
-15 microns	10.78 to 18.23.

Physical measurements on sized fractions of Italian talc showed the coarser particle fractions to have lower, less desirable, measurements on the lubricity board and the finer fractions to have the larger, more desirable, measurements. The sized fractions with the preferable lubricity were found to have the higher porosity and specific surface and the smaller particle size and bulk density (Table 18).

Lubricity-board studies on Italian talc fabricated to particular size distributions show that the lubricity is controlled by the relatively small amount of comparatively larger grains in an otherwise finer mixture. Lubricity-board studies also show that the lubricity of the Italian talc may be improved by the removal of the coarser size fractions. This is not a simple matter, however, as it involves the variation in size of the abrasive particles.

TABLE 18. SUMMARY OF PHYSICAL PROPERTIES OF SIZED FRACTIONS OF ITALIAN TALC

Tyler Mesh Size	Lubricity-Board Measurements, seconds	Average Diameter, microns	Specific Surface, cm^2/g	Porosity Ratio	Bulk Density, lb/cu ft
Unseparated	0.990	2.60	8392	0.448	23.030
+200	0.889	7.40	2948	0.401	34.261
-200+250	0.951	3.60	6061	0.426	26.645
-250+270	0.980	2.50	8727	0.439	20.721
-270+325	1.030	2.35	9284	0.446	19.335
-325+400	1.043	2.25	9697	0.442	19.139
-400	1.099	2.10	10390	0.455	16.894

Measurements on flotation products show that the removal of the small per cent of contaminants improves the lubricity of the talc .

The physical properties of the Italian talc can be improved, with the least possible loss of sample, by removing the mineral contaminants from either the coarse fractions or from the sample as a whole. This appears to be one clear cut course to follow in improving the Italian talc.

(The original notes on the laboratory work described in this report are in Battelle Laboratory Record Books No. 12667, pages 1 through 71, and No. 13034, pages 1 through 77. The work was done in the period from November 7, 1956, to September 30, 1957.)

BIBLIOGRAPHY

(1) Sclar, C. B., et al., "A Review and Appraisal of the Literature on Talc Deposits of the United States", Battelle Report to Johnson and Johnson (May 11, 1955).

(2) Sclar, C. B., et al., "An Investigation of Selected Talc Deposits of the United States", Battelle Report to Johnson and Johnson (February 29, 1956).

(3) Smith, W. L., and Snider, R. H., "Investigation of the Salgada and Casa Nova Talc Deposits of Brazil", Battelle Report to Johnson and Johnson (May 28, 1957).

(4) Smith, W. L., Letter Report to Johnson and Johnson on the Talc Deposits of Madoc, Canada (July 25, 1957).

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APPENDIX A

DESCRIPTION OF LUBRICITY BOARD
AND TECHNIQUE OF OPERATION

APPENDIX A

DESCRIPTION OF LUBRICITY BOARD AND TECHNIQUE OF OPERATION

The experimental device described as the lubricity board in this report consists of a wooden plane inclined at 25 degrees, which is lightly, but completely, covered with talc. The lubricity is determined by measuring the time it takes a steel puck to slide over two microswitches which actuate an electric timer.

The inclined plane is made of 6-ply birch plywood, 3/4 inch thick, 6 inches wide, and 6 feet long. The even-grained wood was sanded smooth to prevent the grain from influencing the descent of the puck. Twenty-five degrees was selected as the inclination from horizontal after much experimentation which showed it to be the minimum angle at which a sustained slide could be made on all of the Italian talc samples.

The microswitches are located 6 inches from each end of the slide, in the middle of the board, making the measured path a length of 5 feet. The microswitches are connected to a double-pole, 115-volt, Struthers-Berm lock-in relay which actuates a Standard Electric Time Company electric timer. The steel puck weighs 226 grams, is 3/4 inch by 2-1/2 inches, has rounded edges, and presents a circular sliding surface of 1-3/4 inches diameter. Such are obtainable from amusement equipment distributors as a piece used in the game of American Shuffleboard. One flat surface of the puck was ground smooth and polished for the lubricity experiments.

The talc is applied to the lubricity board from a 9-ounce Johnsons' Baby Powder can until a thin even layer is present over the measured path. The puck is manually released from a dead start from the top of the slide, 6 inches above the first microswitch. For purposes of eliminating errors of freak descents, lubricity is measured as the average of 50 runs. The board is newly covered with talc after each 10 runs, although no difference in lubricity measurements could be accounted for between those early and late in a series. The puck was washed in warm water and thoroughly dried between runs.

APPENDIX B

PROCEDURE FOR PARTICLE-SIZE ANALYSIS

APPENDIX B

PROCEDURE FOR PARTICLE-SIZE ANALYSIS

In a previous report to Johnson and Johnson from Battelle[2] a procedure for sizing Italian talc was outlined. For purposes of the present investigation, the following procedure was developed by D. A. Jacobs of the Battelle staff.

One hundred grams of talc is wet screened at 325 mesh with water. The +325 mesh product is dried and dry screened on a Ro-Tap for 30 minutes producing +200, 200 x 325, and -325 mesh fractions. The -325 mesh fraction of the dry screening is combined with the -325 mesh product of the wet screening. A suspension of -325 mesh material is allowed to settle through a 10-centimeter column in a 4-liter beaker to which sodium silicate has been added in the amount of 1 pound per ton, and agitated for a period of 10 minutes. The sodium silicate is added to the first 30-minute settling of each sample only. At the end of the first 30-minute cycle, the supernatant column of liquid is siphoned off. This liquid contains the -15 micron fraction. Four cycles are required to remove the -15 micron fraction entirely. Another series of 4 cycles with settling times of 5 minutes produces the 15 x 30-micron fraction, which is siphoned off, plus sands of 30 microns x 325 mesh. The sands are dried and dry screened at 400 mesh on a Ro-Tap for 30 minutes, producing 325 x 100 mesh and 400 mesh x 30 micron fractions. The sizing flowsheet is presented as Figure B-1.

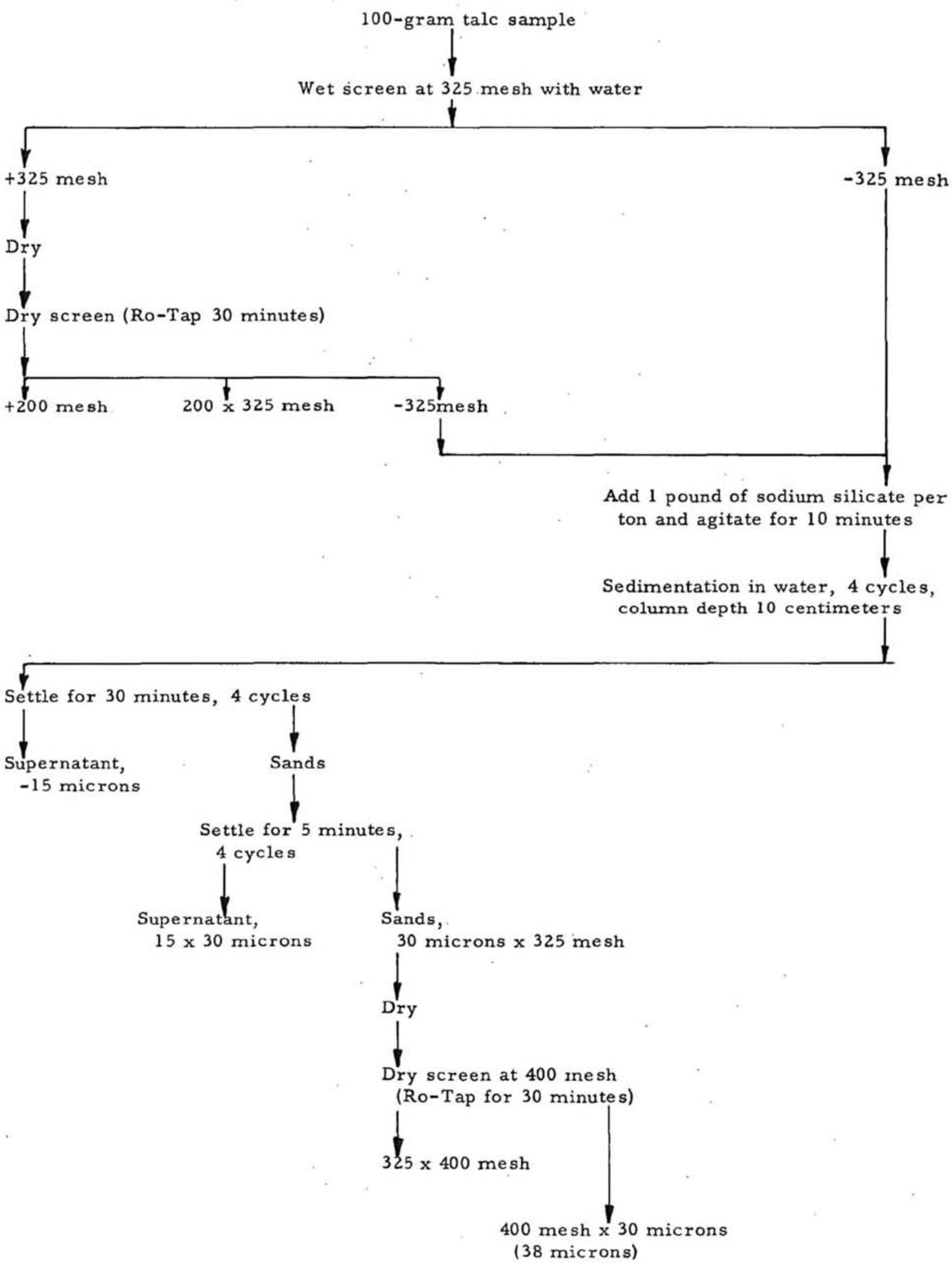

FIGURE B-1. STANDARD FLOWSHEET FOR SIZING OF TALC SAMPLES